Title: phosphor and light source comprising such a phosphor

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5   **Technical field**

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The invention is based on a phosphor and light source having such a phosphor ~~in accordance with the preamble of claim 1~~. It relates in particular to a garnet-based
10   phosphor which is suitable for use in light sources such as LEDs and lamps.

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Prior art

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15   DE-U 201 08 013 has already disclosed a phosphor and light source comprising such a phosphor, in which a phosphor is a garnet of defined rare earths. The use of various rare earths provides the option of setting the color locus of the phosphor within certain limits.
20   However, phosphors of this type, if Y is not the main component of the lattice site occupied by rare earths, are relatively unstable or rather inefficient or have only a low absorption capacity. Although Al may be partially replaced by Ga in the garnet, in particular
25   with these known phosphors with a color locus in the green spectral region, the excitability and consequently also the efficiency of the conversion are not satisfactory. A further restriction on the desired color locus of a known garnet phosphor aimed at
30   realizing a white LED is that a relatively high cerium concentration tends to be required for this purpose, but this can only be realized with very considerable difficulty in terms of manufacturing technology.

35   Hitherto, a combination of a plurality of phosphors has had to be used to realize defined color loci corresponding, for example, to a neutral white or warm white luminous color. This two-component system in principle has a number of drawbacks: the longer-wave

phosphor generally absorbs the emission of the shorter-wave phosphor. Furthermore, the particle sizes of the phosphors have to be matched to one another so that no agglomeration or sedimentation occurs. An additional factor is that the phosphors have to be very homogeneously mixed in an exact mixing ratio in order to avoid color locus fluctuations. Finally, the known phosphors generally have different temperature dependencies, which can result in a color locus drift in the event of the LED being dimmed or at different ambient temperatures.

Summary of the invention

It is an object of the present invention to provide a phosphor ~~in accordance with the preamble of claim 1~~ which is distinguished by being robust and highly sensitive in terms of the selection of color locus within a wide range of the chromaticity diagram.

A further object is to produce a highly efficient, stable green phosphor with a garnet structure for use in LEDs with full-color capability based on a primary LED which emits at a short wavelength, for example in the blue, with a long service life.

A further object is to produce a highly efficient garnet phosphor with an accurately matched color locus for photon excitation, in particular by white LEDs, and also to provide a light source, in particular a white LED with a neutral to warm white luminous color and with just one phosphor as converter. If a single phosphor is used, it is possible to restrict fluctuations in color locus and to simplify production, since there are no mixing and sedimentation problems. Of course, the phosphor can also be used together with other phosphors to provide a light source.

This object is achieved by ~~the characterizing features~~

~~of claim 1. Particularly advantageous configurations are given in the dependent claims~~ a phosphor with a garnet structure of type $A_3B_5O_{12}$:D, characterized in that part of component B is replaced by Si in a proportion x, it being possible for at least one further component (KA, KB, KC) to be incorporated for charge compensation where A = rare earth and B = Al, Ga alone or in combination, and D = rare earth. In one embodiment x = 0.1 to 0.5.

The substitution of component B, in particular Al^{3+}, by Si^{4+} in accordance with the invention leads to a pronounced color locus shift in phosphor systems with a garnet structure, for example Y(Al, Ga)G:Ce. In this context, a further component is normally always required for reasons of charge compensation, since Si is a tetravalent ion, but component B, such as for example Al, is a trivalent ion. For this reason, hitherto only the obvious route of replacing Al with other trivalent ions, such as Ga or In, which occupy the same lattice site, has ever been investigated.

There are a number of ways of realizing this. In a first embodiment, an ion KB which occupies the same lattice site but has a valence of less than 3, i.e. a monovalent or divalent ion, such as for example Mg^{2+}, is introduced simultaneously with Si. Another possible option is Be^{2+}, for example. In these cases, the replacement ion KB is often introduced as an oxide, so that no further charge compensation is required on account of the garnet structure.

In a second embodiment, a different route is taken, in that an ion KC which occupies a different lattice site of opposite charge polarity is introduced simultaneously with Si. On account of the different charge polarity, in this case, there is no restriction on the choice of valence. In this case, it is particularly preferable for oxygen (to be understood as

meaning O^{2-}) to be replaced by nitrogen (to be understood as meaning N^{3-}).

In a third embodiment, an ion KA which occupies a different lattice site, namely that of component A, is introduced simultaneously with Si. In this case, the charge polarity is once again the same as that of Si. Examples of suitable candidates include Na and Li.

In a fourth embodiment, no further ion is introduced with Si, but rather the charge compensation is effected by means of vacancies (designated in accordance with Kröger-Vink as V_A or V_B or V_C if the vacancy is at the lattice site of A, B or O), which are considered to have their own valence of zero.

In general terms, ions whose radius is as close as possible to the radius of the ion to be replaced are preferably suitable. In practice, it has been found that if the radius is larger the limit for this is 30%, i.e. a radius which is 1.3 times greater. In the case of an ion whose radius is smaller than that of the ion to be replaced, this limit is much less critical.

The substitution while maintaining the garnet structure has nothing to do with the new types of nitridosilicates, which, although they may be composed of similar individual components, have a completely different stoichiometry, lattice structure and emission performance; a typical lattice structure is α-sialon, cf. "On new rare-earth doped M-Si-Al-O-N materials", van Krevel, TU Eindhoven 2000, ISBN 90-386-2711-4, Chapter 2.

In detail, in the case of simultaneous charge compensation by exchanging O^{2-} for N^{3-}, a significantly shorter-wave emission is found than for a corresponding garnet with conventional partial replacement of the Al with Ga, i.e. Y(Al, Ga)G:Ce, as has hitherto been known

from the literature. The high quantum efficiency of the
pure YAG:Ce phosphor is in this case virtually
retained. By way of example, it is possible to
synthesize phosphors containing 4 mol% of cerium as
activator and with a dominant wavelength of between
559 nm and 573 nm with a quantum efficiency of
approx. 85 – 90%. Without the use of silicon, the
cerium doping would have to be very greatly reduced to
achieve comparable dominant wavelengths. With a 4%
cerium doping, in practice 563 nm was the shortest
dominant wavelength achieved. The cerium doping is in
the range from 0.1 to 10%.

Surprisingly, the substitution acts differently in pure
Al-containing garnet phosphors of the (Y, Tb, Gd)AG:Ce
type. Slight substitution (< 1 mol%) of Al by Si in
YAG:Ce makes it possible to shift the dominant
wavelength a few nanometers toward longer wavelengths
without the efficiency of the phosphor decreasing. As a
result, it is possible to "optimally" set the white
color locus of the standard white LED without having to
use a second, generally less efficient phosphor for
color locus correction.

If the silicon content is increased to up to 20 mol%,
in particular in the range from 1 – 20 mol%, preferably
up to 10 mol%, an ever more clearly visible red cerium
emission is obtained. As a result, the dominant
wavelength is shifted to up to 584 nm. It is found that
when using a phosphor of this type, by way of example,
it is possible to produce a warm white LED with a color
temperature of approx. 3200 K and an Ra value around
75 – 80 with just one phosphor. The quantum efficiency
of the phosphor rises with a decreasing Si content.
Therefore, the corresponding LED efficiency rises with
an increasing color temperature. It is possible to
realize light sources which are in the range of
luminous colors from similar to daylight through
neutral white to warm white, in particular in the color

temperature range from 2600 to 6500 K.

In this context, of course, the term garnet structure is also intended to encompass a structure which deviates slightly from an ideal garnet and is based on vacancies or lattice disturbances, provided that this crystal retains the typical garnet structure.

A typical phosphor according to the invention has the ideal garnet structure $A_3B_5O_{12}$:D with the novel basic modification ~~$A_{3-u}B_{5-v}Si_xO_{12-w}$:D,~~ in which Si is positioned only on the lattice site of component B, and charge neutrality needs to be maintained, for example realized as ~~A3B5 xSixKyO12 y:D~~ $A_3B_{5-x}Si_x(KA,KB,KC)_yO_{12-y}$:D, with

A = rare earth (RE) selected from the group consisting of Y, Gd, Tb, La, Lu, individually or in combination;

B = Al, Ga, individually or in combination;

D = activator which replaces RE, selected from the group consisting of Ce, Pr, Eu, individually or in combination;

~~K~~ (KA, KB, KC) = charge compensator, selected in particular from Mg^{2+}, Be^{2+} and N^{3-}, which compensates for the charge mismatch of the Si.

In this context, in particular the following relationships apply: $0 < x \leq 1$ and $0 \leq y \leq 2x$.

The value of y depends on the specific details of the crystal structure, in particular if ~~K~~ the charge compensator is N, y = x.

In general, it should specifically be taken into account that different lattice sites may have different valencies, and consequently a formation of the modified garnet taking account of possible compensating

components KA on lattice site A, compensating components KB on lattice site B and compensating components KC on the lattice site of the oxygen leads to the general formula

$[A_{3-a}KA_a]_A[B_{5-b-x}KB_bSi_x]_B[O_{12-s}KC_s]_O:D$ in which the activator D is to be counted as part of component A. In other words, therefore, the formula can also be expressed as $[A_{3-t-a\#}KA_{a\#}D_t]_A[B_{5-b-x}KB_bSi_x]_B[O_{12-s}KC_s]_O$. In this formula, a# is a different value than a, which results from incorporating the doping D in a, in a manner which is known per se.

The main condition for the coefficients can in general be presented as follows:

$$a(m_{KA}-3)+b(m_{KB}-3) + x = s(-m_{KC}-2).$$

In the above, m is the respective valence of the incorporated ion of component KA, KB or KC, with any vacancies being assumed to have a valence m = 0.

In this context, there are a plurality of possible embodiments:

Firstly, there is the type in which Si replaces part of element B, with Si being introduced by a ferry, namely an oxygen-replacing mechanism, for example by means of nitrogen, so that the following formula applies for stoichiometry: $A_3B_{5-x}Si_x[O_{12-s}N_s]_O:D$, in which the subscript index O makes a statement about the lattice site O. Here, N is an ion of type KC, with in particular s ≤ 1.5 and x ≤ 1.5, and preferably x = s.

Secondly, there is the type in which Si partially replaces the element B, Si being introduced by a mechanism which compensates for the charge at lattice site B, so that the following formula applies for stoichiometry: $A_3[B_{5-(x+y)}Si_xKB_y]_BO_{12}:D$

$A_3[B_{5-(x+b)}Si_xKB_b]_BO_{12}:D$, in which the subscript index B makes a statement about the lattice site B. By way of example, Si is introduced together with Mg or Na, specifically both via an oxygen compound as ferry, wherein in particular ~~y~~ $b \leq 1$ and $x \leq 1$.

In the case of a different form of introduction of the co-doping ~~K~~ charge compensator, for example by means of nitrogen or another element which replaces oxygen, the resulting stoichiometry gives a mixed form of the first type, i.e. for example ~~$A_3[B_{5-x-y}Si_xKB_y]_B[O_{12-s}N_s]_O:D$~~ $A_3[B_{5-x-b}Si_xKB_b]_B[O_{12-s}N_s]_O:D$. One example is $x = 1$ and ~~y~~ $b = 0.5$ with B as Mg^{2+} and $s = 0.5$.

Thirdly, there is the type in which Si partially replaces the element B, with Si being introduced by an element as a ferry which partially replaces the lattice site A, i.e. being introduced by a mechanism which replaces A, so that the following formula applies for stoichiometry:
~~$[A_{3-y}KA_y]_A[B_{5-x}Si_x]_BO_{12}:D$~~ $[A_{3-a}KA_a]_A[B_{5-x}Si_x]_BO_{12}:D$, in which the subscript index A, B makes a statement about the association with the lattice sites of components A and B. Here, in particular $x = $ ~~y~~ a. This behavior may manifest itself in particular in the case of divalent ions, such as in particular Mg or Be. However, Na and Li are also suitable as KA and are incorporated in monovalent form, in which case in particular ~~y~~ $a \leq 2$ and $x \leq 2$.

Fourthly, there is the type which compensates for the charge compensation solely by the formation of vacancies. In this case, the Si can be associated with vacancies at all lattice sites. The stoichiometry is then: $A_{3-x/3}B_{5-x}Si_xO_{12}:D$, in which in particular $x \leq 0.2$. By way of example, $x = 0.1$.

Of course, mixed forms of all these basic types may also occur. The doping D is normally always to be

considered a constituent of lattice site A.

If B = Al, the value x is preferably between $0.01 \leq x \leq 1$, and in the case of B = (Al, Ga) with a Ga content of at least 20 mol% of B, the value of x is preferably in the range of from $0.05 \leq x \leq 0.25$. Depending on the surrounding conditions, the addition of Si in the garnet structure effects a red or blue shift compared to an Si-free garnet of the same type. Even more surprising is the discovery that the magnitude of the color locus shift is not an unambiguous function of the addition of Si, but rather has more of a dependent relationship. Particularly great shifts can be achieved with relatively low quantities of Si added (x = 0.08 to 0.23). Moreover, however, the behavior in individual cases is also dependent on the charge compensator K, in particular the question of its associated lattice site.

The ion radius of the Si^{4+} is similar to that of the Al^{3+}, and consequently this component is relatively easy to incorporate instead of Al^{3+}. This is one of the main points justifying the surprisingly good replacement function. By contrast, the ion radius of Mg^{2+}, which can serve as a charge compensator here, is significantly larger than that of Al^{3+}, and consequently it is less easy to incorporate instead of Al^{3+}. Therefore, with the system Si^{4+}-Mg^{2+}, only a relatively small quantity of Si^{4+} can be added.

By contrast, the system Si^{4+} with N^{3-} as charge compensator is much less critical, since the nitrogen ion replaces an oxygen ion of approximately the same size. Therefore, with this system a relatively large quantity of Si^{4+} can be added.

It is advantageous that this mechanism can in part also perform the role of the activator D with a view to a shift in the color locus, so that relatively small

quantities of D are required compared to conventional garnets. This applies in particular if D = Ce.

Moreover, the excitability of the new types of phosphor extends over a wide range from approximately 250 nm, preferably 300 nm, up to approximately 550 nm, preferably 490 nm. There are maxima at approximately 350 nm and approximately 460 nm. Therefore, this phosphor is suitable not only for excitation by UV or blue emitting primary light sources, such as LEDs or conventional Hg-based discharge lamps, but also for light sources such as a discharge lamp based on an indium low-pressure discharge or also an indium high-pressure discharge, the resonance lines of which lie, for example, at 304, 325, 410 and 451 nm.

The emission behavior is dependent to a significant extent on the charge compensator. By way of example, the use of nitrogen leads to an increased covalent bond content; in the literature, a behavior of this type is described as what is known as a nephelauxetic effect. An increased crystal field splitting may simultaneously be superimposed on this effect, for example as a result of the higher charge of the N^{3-} ion compared to the O^{2-} ion. The Si^{4+} ion, which is more highly charged than Al^{3+}, additionally influences these effects, in a direction which is dependent on the particular details.

The phosphor according to the invention is eminently suitable for use as a green phosphor.

One particular advantage of the phosphors according to the invention is that they have a relatively low temperature quenching. It is surprising that a tetravalent ion such as Si can be incorporated at the lattice site of a trivalent ion without significant efficiency losses.

Brief description of the drawings

The invention is to be explained in more detail below on the basis of a plurality of exemplary embodiments. In the drawings:

Preferred embodiment of the invention

For use in a warm-white LED together with a GaInN chip, by way of example a similar structure to that described in US 5,998,925 is used. The structure of a light source of this type for white light is specifically shown in figure 1. The light source is a semiconductor component (chip 1) of type InGaN with a peak emission wavelength of 460 nm and a first and second electrical connection 2, 3 embedded in an opaque basic housing 8 in the region of a recess 9. One of the connections 3 is connected to the chip 1 via a bonding wire 14. The recess has a wall 17 which serves as reflector for the primary radiation of the chip 1. The recess 9 is filled with a potting compound 5, which as its main constituents contains an epoxy casting resin (for example 80 to 90% by weight) and phosphor pigments 6 (for example less than 15% by weight). Further small fractions are attributable, inter alia, to Aerosil. The phosphor pigments consist of pigments of silicon-containing garnet. These emit yellow light and are mixed with a remainder of the unconverted blue of the primary radiation to form white. The same structure is also suitable for creating a green-emitting LED, in which case the blue primary radiation is completely converted.

Figure 2 shows part of a surface-light fitting 20 as illumination unit. It comprises a common support 21, to which a cuboidal outer housing 22 is adhesively bonded. Its upper side is provided with a common cover 23. The cuboidal housing has cutouts in which individual semiconductor components 24 are accommodated. They are UV-emitting light-emitting diodes with a peak emission of typically 340 nm. The conversion into white light takes place by means of conversion layers which are positioned directly in the casting resin of the individual LEDs, in a similar manner to that described in figure 1, or layers 25 which are arranged on all surfaces which are accessible to the UV radiation.

These include the inner surfaces of the side walls of the housing, of the cover and of the base part. The conversion layers 25 consist of three phosphors which emit in the red, green and blue spectral regions using
5   the phosphors according to the invention.

First of all, Table 1 shows ion radii of a few important elements which are incorporated in the garnet. The relative quantum efficiencies QE of some Si
10   garnets of type ~~Y(Al3 xSixGa2)O12:Ce~~ $Y(Al_{3-x}Si_xGa_2)G:Ce$ (4%) are shown in Table 2.

Figure 3 shows the emission spectrum of a warm-white LED which uses a single Si garnet as conversion agent.
15   The primary radiation is 460 nm, resulting in a color temperature of 3250 K and a color rendering index of 80.

Fig. 4 shows the reflectance of an Si garnet as a
20   function of the wavelength. This garnet is ~~Y3Al4.9Si0.1O11.9N0.1:Ce~~ $Y_3Al_{4.9}Si_{0.1}O_{11.9}N_{0.1}:Ce$.

Figure 5 shows the emission properties of an Si garnet (x = 0.25), namely ~~Y3Al4.75Si0.251O11.75N0.25:Ce~~
25   $Y_3Al_{4.75}Si_{0.251}O_{11.75}N_{0.25}:Ce$, as a function of the wavelength (in nm) in direct comparison with the emission properties of the same garnet without the addition of Si (x = 0), namely YAG:Ce. The considerable shift in the peak wavelength is amazing. A typical
30   value for the cerium doping is from 0.5 to 4% of A.

Figure 6 shows the emission properties of the Si garnet ~~Tb(Al4.5Si0.5)O11.5N0.5:Ce~~ $Tb_3(Al_{4.5}Si_{0.5})O_{11.5}N_{0.5}:Ce$ as a function of the wavelength. Figure 7 shows the emission
35   properties of the Si garnet ~~(Y0.55Gd0.45)(Al4.5Si0.5)O11.5N0.5:Ce~~ $(Y_{0.55}Gd_{0.45})_3(Al_{4.5}Si_{0.5})O_{11.5}N_{0.5}:Ce$ as a function of the wavelength.

Figure 8 shows the shift in the dominant wavelength (nm) as a function of the content x of Si at 460 nm for the phosphor ~~Y(Al5-xSix)(O12-xNx):Ce~~ $Y_3(Al_{5-x}Si_x)(O_{12-x}N_x):Ce$. Surprisingly, the maximum is at

5 approximately 0.25. Therefore, the function is not linear.

Figure 9 shows the change in the efficiency and emission width of various phosphors of type

10 ~~Y2.88Ce0.12Al5O12~~ $Y_{2.88}Ce_{0.12}Al_5O_{12}$ (i.e. YAG:Ce) when AlO is exchanged for SiN.

Figure 10 shows the change in efficiency and emission width for various phosphors of type

15 ~~Y2.88Ce0.12Al3Ga2O12~~ $Y_{2.88}Ce_{0.12}Al_3Ga_2O_{12}$ (i.e. Y(Al,Ga)G:Ce) when Si is added as SiN as a replacement for AlO. Surprisingly, the addition of gallium makes the properties of this system completely different from those of pure YAG:Ce.

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Figure 11 shows the emission properties of an Si garnet (x = 0.25) as a function of the wavelength (in nm) as a direct comparison with the emission properties of the same garnet without the addition of Si (x = 0)~~, namely~~

25 ~~Y3Al2Ga2:Ce~~. Not only the great shift in the peak wavelength but also the fact that this shift is in precisely the opposite direction to in figure 5, are amazing. The details of this unusual behavior are not yet fully understood.

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Figure 12 shows the shift in the dominant wavelength (nm) as a function of the content x of Si at 460 nm excitation for the phosphor ~~Y(Al3-xGa2Six)O12:Ce~~ $Y_3(Al_{3-x}Ga_2Si_x)O_{12}:Ce$. Surprisingly, the maximum is at

35 approximately 0.25, and therefore the function is not linear.

Figure 13 shows the chromaticity diagram (CIE) with the coordinates x, y for a system composed of blue LED

(peak emission at 450 to 470 nm) and Si garnets according to the invention. It can be seen that in the case of conventional garnets, it is now possible for the first time to realize systems with a warm-white

5 luminous color of typically 3200 or 2850 K or below in a simple way by means of a single phosphor. Candidates for this phosphor are in particular Si garnets based on the garnets (unshaded triangles) of the rare earths Y, Tb and Gd, which can be shifted to the right toward

10 longer wavelengths by means of the addition of Si (solid triangles). Conversely, green LEDs can be successfully realized by adding Si to Ga-containing garnets (Al:Ga ratio is preferably between 0.5 and 2.5), starting from YAG:Ce, in which case the peak

15 wavelength migrates to the left toward shorter wavelengths.

Therefore, Si garnets are ideally suited to being specifically adapted to customer's requirements.

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Figure 14 shows an X-ray diffractogram for YAG:Ce with an Si content x = 0.1, which illustrates the typical garnet structure, compared to conventional YAG:Ce, cf. lower bar. Figure 15 shows the same for a Si

25 content of x = 0.25.

Figure ~~16~~ 17 shows an X-ray diffractogram for ~~YAl3Ga2O12:Ce~~ $Y_3Al_{3-x}Ga_2Si_xO_{12}$:Ce with a Si content x = 0.25, which illustrates the typical garnet structure,

30 compared to conventional YAG:Ce, cf. the lower bar, with an yttrium oxynitride being indicated as a second bar, but the structure of this material is not suitable for the phosphor under investigation. Figure ~~17~~ 16 shows the same for an Si content of x = 0.5.

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A typical production process is fundamentally based on the standard production of YAG:Ce, with the following example of a modification:

The batch is selected as follows in accordance with Table 3:

This batch is mixed for approx. 40 min in a mortar
5   mill; it is then calcined at 1460 – 1560°C for several hours (typically 3 h). The precise temperature depends on the composition and in particular on the addition of flux. Boric acid H_3BO_3 is typically added.

10   Figure 18 shows a further application, as is already known in principle from US-B 6,700,322. In this case, the phosphor according to the invention is used in combination with an OLED. The light source is an organic light-emitting diode 31, comprising the actual
15   organic sheet 30 and a transparent substrate 32. The sheet 30 emits in particular blue primary light, generated for example by means of PVK:PBD:Coumarin. The emission is partially converted into yellow, secondary emitted light by a covering layer, formed from a layer
20   33 of the phosphor according to the invention, so that overall a white emission is realized by color mixing of the primary and secondary emitted light. It is preferable for the phosphor according to the invention to interact with a blue-green primary emission. This
25   means that the primary emission is at 480 to 505 nm peak wavelength. It may particularly preferably also be realized by an organic phosphor sheet which has two peaks, one in the blue at 430 to 490 nm and another at 495 to 520 nm, so that overall the dominant wavelength
30   is in the blue-green. This system achieves amazing color rendering values (Ra better than 85) at a color temperature of from 4000 K to 4600 K using just two phosphors (the sheet and the modified garnet phosphor). The OLED substantially comprises at least one layer of
35   a light-emitting polymer or of what are known as small molecules between two electrodes, which consist of materials that are known per se, such as for example ITO as anode, and a highly reactive metal, such as for example Ba or Ca, as cathode. A plurality of layers are

often also used between the electrodes, serving either as a hole transport layer (for example Baytron-P, commercially available from HC Starck) or also serve as electron transport layers in the region of the small

5   molecules.

The emitting polymers used are, for example, polyfluorenes or polyspiro materials.

10   A further application for the phosphor according to the invention is in fluorescent lamps, where it is applied to the inner side of the bulb, as is known per se, if appropriate in combination with further phosphors which are known per se, such as for example halophosphates.

15   In this case, the excitation is effected by means of the known Hg lines, in particular at 254 nm.

One specific application is an indium lamp. Figure 19 shows a low-pressure discharge lamp 20 50 with a

20   mercury-free gas fill 21 51 (in the form of a diagrammatic illustration) which contains an indium compound and a buffer gas similar to WO 02/10374, with a layer 22 52 of Si-containing garnet having been applied to the lamp wall 53. The very particular

25   advantage of this arrangement is that this modified garnet is well matched to the indium radiation, since the latter has significant components both in the UV and in the blue spectral region, both of which are equally well absorbed by this garnet, which makes it

30   superior to the previously known phosphors for this application. These known phosphors significantly absorb either only the UV radiation or the blue radiation of the indium, and consequently the indium lamp according to the invention is significantly more efficient. This

35   statement also applies to an indium lamp based on high pressure, as is known per se from US 4,810,938.

A further application is excitation in electroluminescent lamps by a blue or blue-green

emitting electroluminescent phosphor with a peak emission between 440 and 520 nm.

Figure 20 shows the good long-term stability of a warm-white LED using the phosphor discussed in figure 3. Both the light flux (figure 20a) and the color coordinates x and y (figures 20b, 20c) remain virtually stable over 500 hours.

Table 1 ion radii (typical value) in nm

	CN4 tetrahedral	CN6 octahedral
Mg^{2+}	–	0.07
Al^{3+}	0.04	0.05
Ga^{3+}	0.05	0.06
Si^{4+}	0.04	0.05
O^{2-}	0.12	0.13
N^{3-}	0.13	0.17

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Table 2 relative quantum efficiency for $Y(Al_{3-x}Si_xGa_2)G:Ce$ at 460 nm excitation

X (Si)	rel. QE in %	Dominant wavelength (nm)
0	100	566
0.25	101	559
0.50	103	560
0.75	100	561

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Table 3

Component	Purity	Source of procurement
Y_2O_3	4N	Rhodia
CeO_2	3N5	Rhodia
Al_2O_3	4N	Alfa A
Ga_2O_3	5N	Alfa A
SiO_2	Aerosil	Ox 50
H_3BO_3		Merck